XXII International Baldin Seminar

A.M. Baldin seminar series

The Beginning of Dubna

- Sources:
- Igor Golovin’s biography of Igor Kurchatov
- V. P. Dzhelepov’s article in HISAP ‘96 “when Dubna was not on the map”
- B. L. Ioffe’s article in HISAP ‘96 “Why the ‘tube’ did not proceed, the heavy water reactor at ITEF”

Veksler and Phase Stability

- Soon after Veksler’s discovery in 1944, Kurchatov became convinced that a high energy proton accelerator could and should be built in the USSR.
- In 1946 Kurchatov proposed to the government that such a facility be constructed.

Beria takes control

- The Soviet government in 1946 authorized the construction of a synchrocyclotron of 500-700 MeV.
- A site selection committee was chosen by Beria.
- A. I. Mintz gave the selection committee recommendation to Beria.

Mintz’s recommendation

- Two sites were deemed suitable.
- The Kryukovo region about 40 km from Moscow (in the direction of Dubna, but closer, near Sheremetevo airport.)
- A site near the village of Novo-Ivankovo, 125 km from Moscow, where Dubna now is.
- Mintz preferred the Kryukovo site.

Site selection

- Beria chose Novo-Ivankovo, near the first locks of the Volga-Moscow canal, on the banks of the Volga River.
- Mintz said the place was swampy. Beria said we will drain it. Mintz said there was no railroad. Beria said we will build one. Mintz said there was not enough electric power. Beria said we will build a new power station.

Beria wins

- One important factor in the choice was the remoteness of the site. Another was that cooling water was available from the Volga. A third was the proximity of a prison camp which supplied construction labor.
- Kurchatov chose two of his best co-workers for the cyclotron construction – V. P. Dzhelepov and M.S. Kozodaev.
- The laboratory was called the Hydrodynamics Laboratory of the USSR Academy of Sciences.The director was M.G. Mesheryakov.

Construction goal was met

- The synchrocyclotron, with a magnet diameter of 5 m, was commissioned in December, 1949, in time for Stalin's 70^{th} birthday.
- Dubna remained a secret town until the mid '50's.
- All nuclear research in the USSR was classified.

W pair production at the Tevatron

Lee Pondrom
University of Wisconsin
For the CDF Collaboration

Data analyzers

- The WW analysis presented here was performed by Matt Herndon and Will Parker of the University of Wisconsin. Will Parker presented the results at ICHEP 2014 in Valencia, Spain.

Will Parker’s talk

Measurement of the W^+W^- Production Cross Section and Differential Cross Sections with Jets in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV

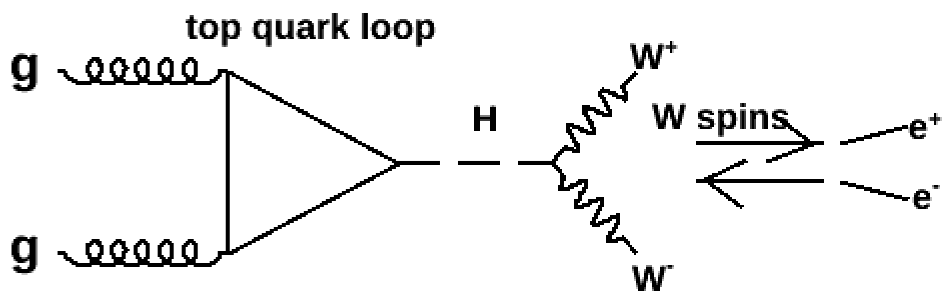
William C. Parker

U.W. Madison

on behalf of the CDF Collaboration

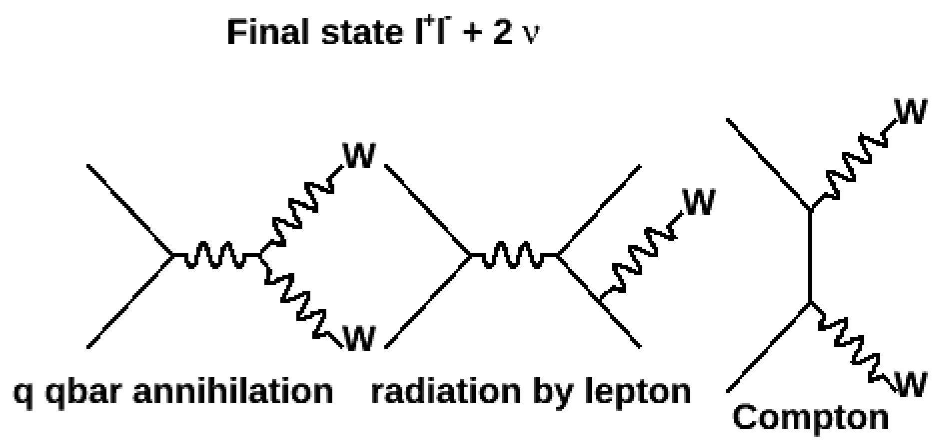
37^{th} International Conference on High Energy Physics
Valencia, Spain, July 2-9, 2014

W pair analysis started by Higgs search

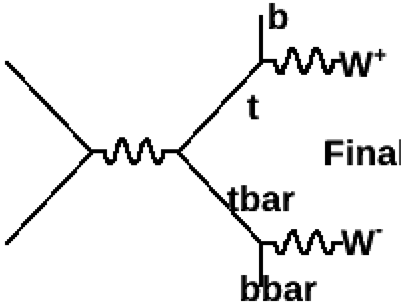


Spin 0 H -> parallel charged leptons

Higgs decay is one source of W pairs other sources: off quarks s & t channel



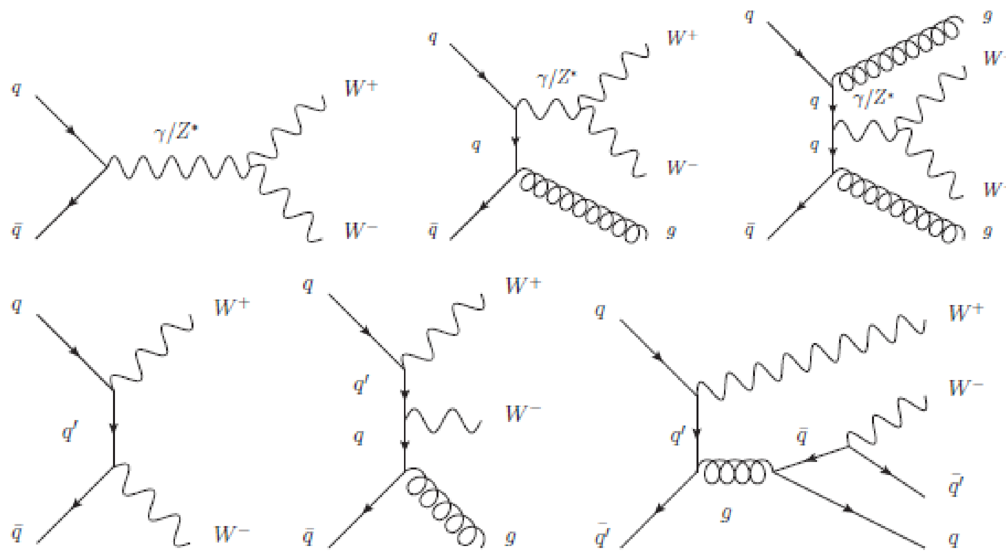
Another source ttbar pairs



Final state l^+l^- + 2ν + 2 b jets

WW + jets Diagrams

Motivation



- Differential measurement of the WW cross section for 0, 1, and 2 jets
- Comparison to leading simulations techniques including
  - LO order with N hard jets (fixed order) + parton shower
  - NLO + parton shower

Previous measurements

WW Measurements

$\sqrt{s}$	Experiment	Luminosity	Cross Section	Prediction	Jet Info
1.96 TeV	D0	1.1fb^{-1}	11.5 ± 2.2 pb	12.7 ± 0.7 pb	Inclusive
	CDF	3.6fb^{-1}	$12.1^{+1.8}_{-1.6}$ pb	11.7 ± 0.7 pb	Veto $E_T > 15$ GeV
7 TeV	ATLAS	4.6fb^{-1}	51.9 ± 4.8 pb	44.4 ± 2.8 pb	Veto $p_T > 25$ GeV
	CMS	4.9fb^{-1}	52.4 ± 5.1 pb	47.0 ± 2.0 pb	Veto $E_T > 30$ GeV
8 TeV	ATLAS(new)	20.3fb^{-1}	$71.4^{+5.6}_{-5.0}$ pb	$58.7^{+3.0}_{-2.7}$ pb	Veto $p_T > 25$ GeV
	CMS	3.5fb^{-1}	69.9 ± 7.0 pb	$57.3^{+2.3}_{-1.6}$ pb	Veto $p_T > 30$ GeV

Add Citations

- Previous W^+W^- measurements
- Inclusive or jet veto
- Consistent with predictions at the $\sim 2\sigma$ level

W decays

- We restrict the final state to leptonic decays
- $W^+ \to \mu^+ \nu_\mu$
- $W^+ \to e^+ \nu_e$
- $W^+ \to \tau^+ \nu_\tau$; $\tau^+ \to \mu^+ \nu_\mu$ ($e^+\nu_e$) ν_τ - smaller acceptance
- Charge conjugates for W^- . So the final state is
- l^+l^- + 2 ν's (missing E_T) + possible jets from initial state radiation, or from top quarks(background).

Data sets

Event Selection

- Loose kinematic selection, with multivariate discriminant
- Two oppositely charged leptons
  - Single high $E_T (p_T)$ electron or muon trigger
  - Lepton categories maximize fiducial acceptance
  - Isolation requirement to reduce misidentified objects
- Two neutrinos

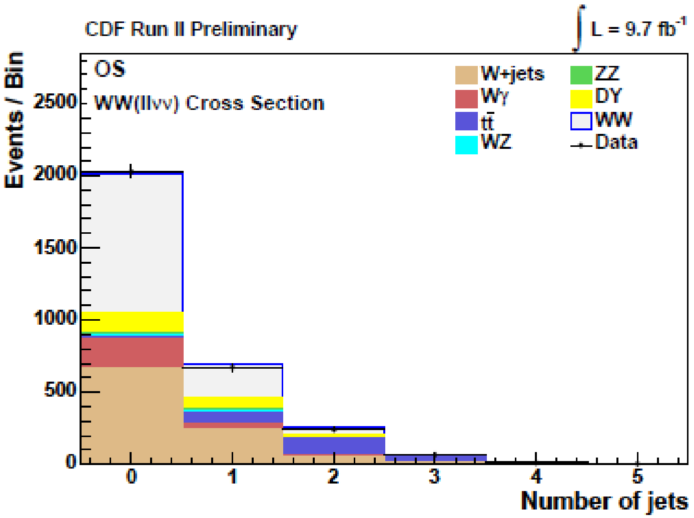
$$\not{E}_{T,rel} \equiv \begin{cases} \not{E}_T & \text{if} \Delta\phi(\vec{\not{E}}_T, lepton, jet) > \frac{\pi}{2} \\ \not{E}_T sin(\Delta\phi(\vec{\not{E}}_T, lepton, jet) & \text{if} \Delta\phi(\vec{\not{E}}_T, lepton, jet) < \frac{\pi}{2} \end{cases}$$

  - Reduces significance of $\not{E}_T$ aligned with mismeasured object
- Jets
  - 0 Jet
  - 1 Jet - further separated:
    - ★ $15 < E_T < 25$ GeV
    - ★ $25 < E_T < 45$ GeV
    - ★ $E_T > 45$ GeV
  - 2 or more jets: b-tag veto

Signal and background

Signal and Background Modeling

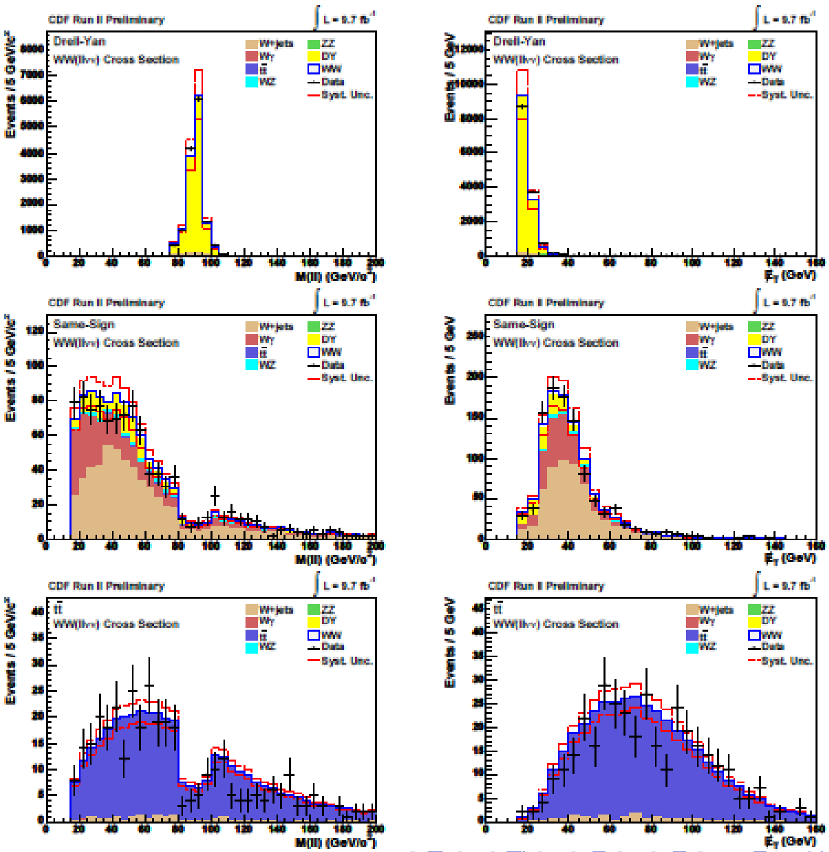
- Shared final state
  - $WZ, ZZ, t\bar{t}$
  - Simulated with Pythia
- Mismeasured $E_T(p_T)$
  - Drell-Yan
  - Simulated with Pythia and Alpgen
- Misidentified particle
  - $W\gamma$ - simulated with Baur MC, data driven scaling
  - W+jets - data driven method
- WW simulated with Alpgen, verified with MC@NLO



Control regions

Control Regions

- Drell-Yan
  - m_{ll} near Z mass
  - No $e\mu$ events
  - Relax $\not\!\!E_{T,rel}$
- Same Sign
  - Same sign leptons
  - W+jets, $W\gamma$
- $t\bar{t}$
  - At least 2 jets
  - At least 1 b-tag



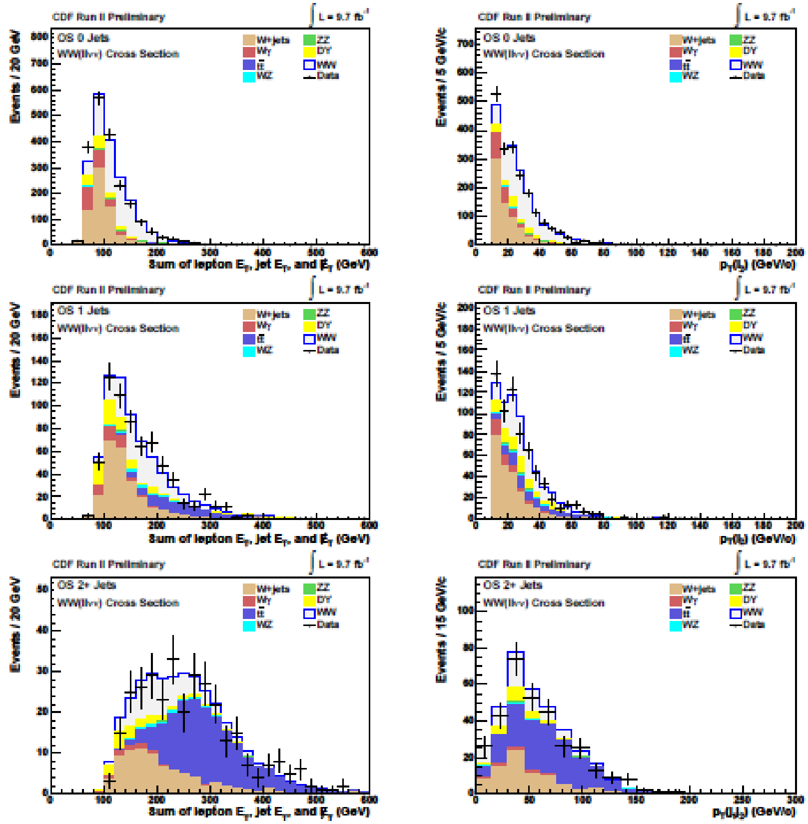
Top quarks

- σ(pbar p -> tbar t) at 1.96 TeV ~ 2/3 σ(WW)
- tbar t -> W^- W^+ + bbar b (two heavy flavor jets)
- Therefore tbar t is a big problem in any measurement of σ(WW + jets)
- Handles: secondary vertex b tagger veto leaves about 25% untagged; and the total E_T in the event ~ 300 GeV, twice that of WW.

Neural network

Neural Network Method

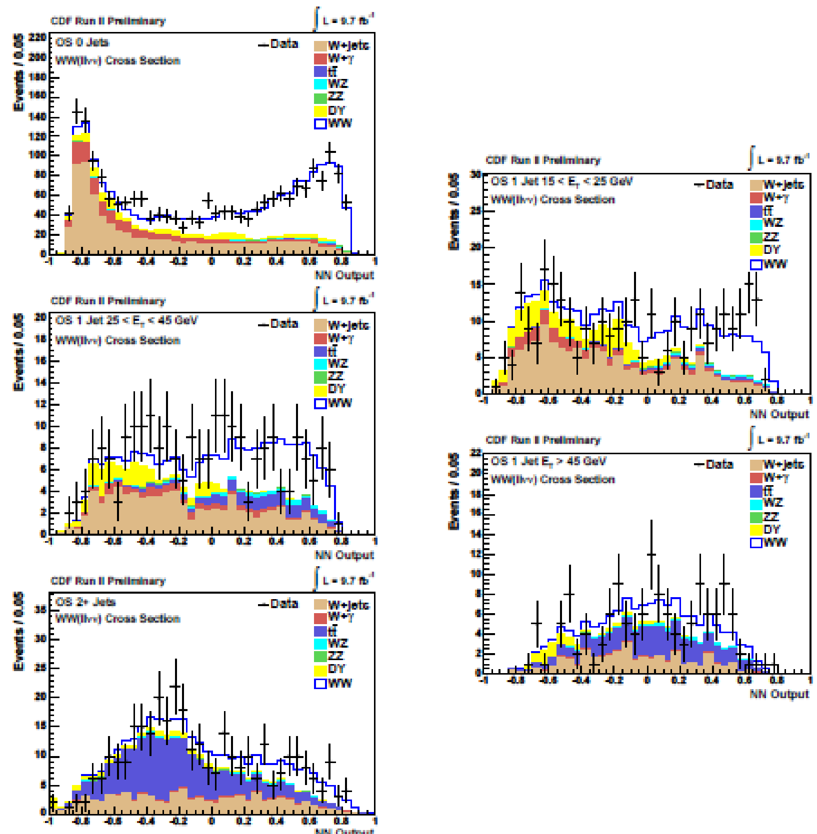
- Neurobayes® neural networks
- 0, 1, 2 Jets
- Kinematic inputs
  - Scalar sum E_T: WW energetic, $t\bar{t}$ even more so
  - $p_T(l_2)$: lower for j/γ misidentification
  - $p_T(j_1 j_2)$: higher for $t\bar{t}$
- 0 Jet: matrix element based likelihood ratio



Neural Net output

Neural Network Outputs

- Each bin fit simultaneously via maximum likelihood method
- Systematics - nuisance parameters with Gaussian constraint
- Signal normalization unconstrained



WW events + background

WW(llνν) Cross Section	CDF Run II Preliminary		$\int L = 9.7\ \text{fb}^{-1}$
Process	Events (Best Fit)		
	0 Jets	1 Jet	2 or More Jets
WZ	19.5 ± 3.0	16.7 ± 2.3	4.26 ± 0.81
ZZ	13.2 ± 1.9	4.25 ± 0.61	1.33 ± 0.26
$t\bar{t}$	3.7 ± 1.0	76 ± 12	158 ± 16
DY	150 ± 34	83 ± 21	20.2 ± 8.6
$W\gamma$	214 ± 27	44.0 ± 6.4	7.5 ± 1.9
W+jets	685 ± 118	250 ± 46	81 ± 15
Total Background	1086 ± 124	474 ± 57	272 ± 26
WW	963 ± 108	224 ± 29	73 ± 20
Signal+Background	2049 ± 177	698 ± 73	345 ± 39
Data	2090	682	331

Systematic uncertainties

Systematics

WW(ll$\nu\nu$) Cross Section — CDF Run II Preliminary — $\int L = 9.7\ \text{fb}^{-1}$

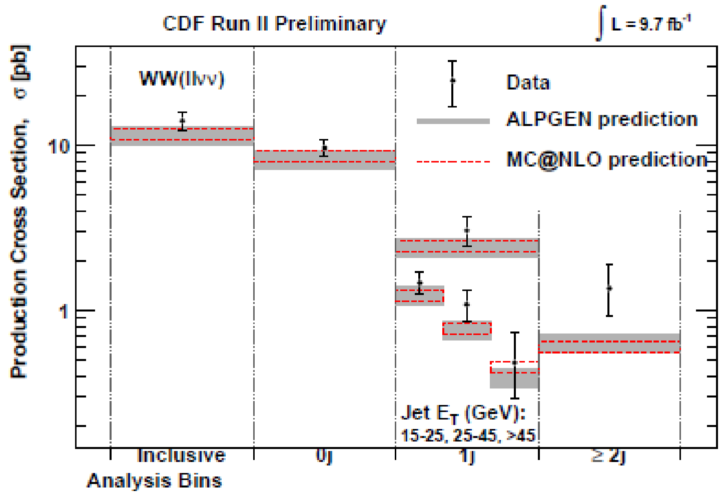
Uncertainty Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jet
Cross Section	6.0%	6.0%	6.0%	4.3%*			
Acceptance							
$\not{E}_T$ Modeling					(19.0-26.0%*)		
Higher-order Diagrams		10.0%	10.0%			10.0%*	
$t\bar{t}$ QCD				2.7%			
Conversion Modeling						6.8%	
Scale	(-23.7-3.8%)						
PDF Modeling	(0.8-1.8%)						
Jet Energy Scale	(-21.5-4.7%)	(-13.2-6.4%)	(-13.3-3.5%)	(-12.9-26.8%)	(-28.7-10.2%)	(-22.0-3.5%)	
$b-$tag veto				(0.0-3.9%)			
Lepton ID Efficiencies	3.8%	3.8%	3.8%	3.8%	3.8%		
Trigger Efficiencies	2.0%	2.0%	2.0%	2.0%	2.0%		
Jet Fake Rate							(17.2-19.0%)
Luminosity	5.9%	5.9%	5.9%	5.9%	5.9%		

* indicates uncorrelated systematic. $(-)$ indicates anticorrelated systematic.

- Dominant systematics
  - Fake Rate
  - $\not{E}_T$ Modeling
  - Parton Showering Scale
  - Jet Energy Scale

Results

Results



- Events migrate due to jet reconstruction, scale, resolution
- Compare clustered hadrons to reconstructed jets
- Correct iteratively to hadronic level via Bayesian method

WW($ll\nu\nu$) Cross Section — CDF Run II Preliminary — $\int L = 9.7\ \text{fb}^{-1}$

Jet Bin	σ(pb) Measured	Uncertainty(pb) Stat.	Syst.	Lumi.	σ(pb) Alpgen	MC@NLO
Inclusive	14.0	±0.6	$^{+1.6}_{-1.3}$	±0.8	11.3 ± 1.4	11.7 ± 0.9
0 Jets	9.6	±0.4	$^{+1.1}_{-0.9}$	±0.6	8.2 ± 1.0	8.6 ± 0.6
1 Jet Inclusive	3.05	±0.46	$^{+0.48}_{-0.32}$	±0.18	2.43 ± 0.31	2.47 ± 0.18
1 jet, $15 < E_T < 25$ GeV	1.47	±0.17	$^{+0.15}_{-0.11}$	±0.09	1.26 ± 0.16	1.18 ± 0.09
1 jet, $25 < E_T < 45$ GeV	1.09	±0.18	$^{+0.17}_{-0.12}$	±0.06	0.77 ± 0.10	0.79 ± 0.06
1 jet, $E_T > 45$ GeV	0.49	±0.15	$^{+0.20}_{-0.11}$	±0.03	0.40 ± 0.05	0.46 ± 0.03
2 or More jets	1.36	±0.30	$^{+0.46}_{-0.29}$	±0.08	0.64 ± 0.08	0.61 ± 0.05

CDF Public Note 11098

conclusions

Conclusion

- We have measured the differential cross section for WW production as a function of jet energy and multiplicity
- We find the WW cross section to be consistent with the Standard Model prediction
- This is the most precise measurement of the WW cross section at a $p\bar{p}$ collider, and the first differential cross section measurement in a massive diboson state

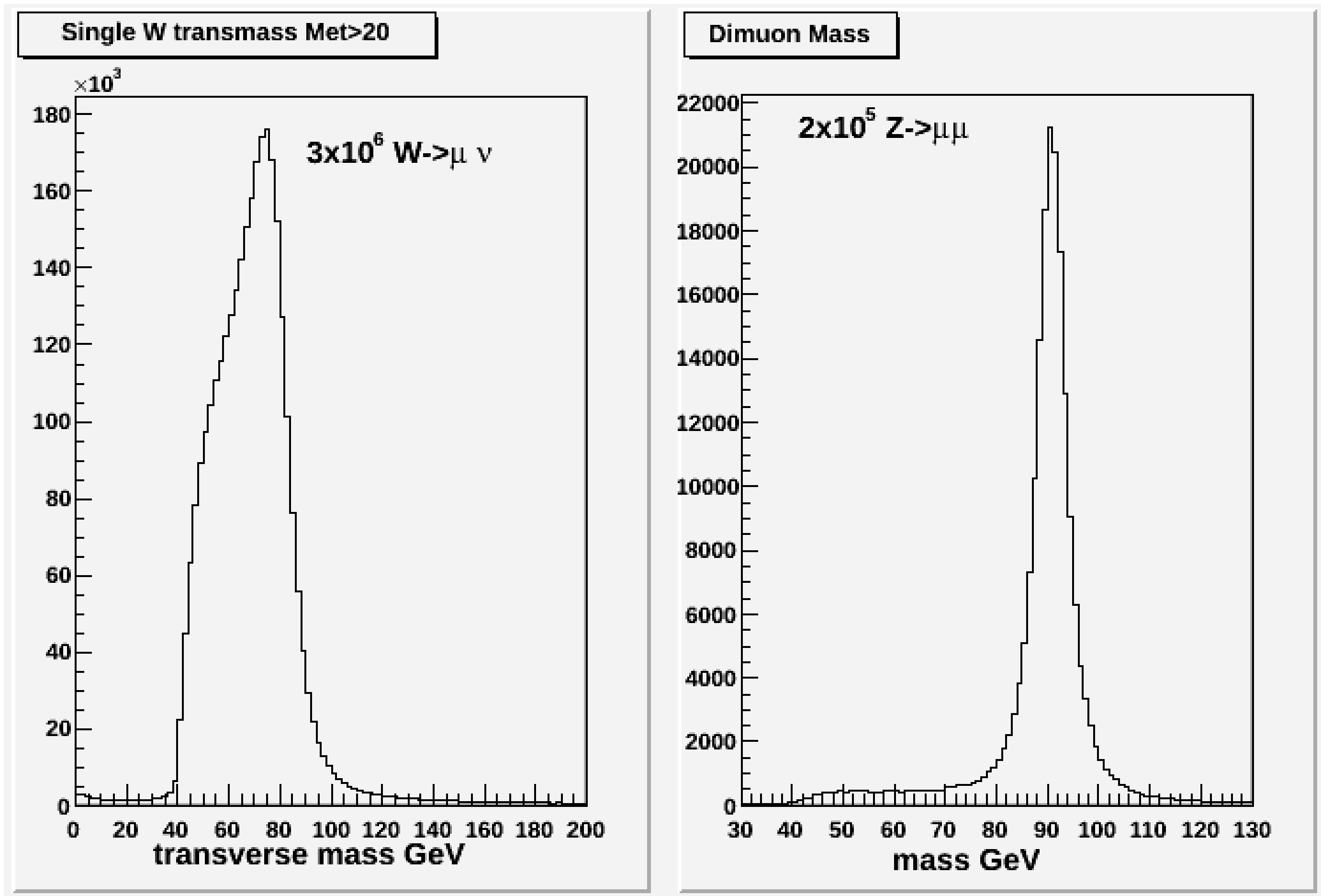
Simplified analysis check

- Look at high p_T muon candidates ($p_T > 18$ GeV)
- $\int L dt = 9.6$/fb good runs
- 3×10^8 events
- Require $p_{T\mu} > 20$ GeV
- Missing $\overrightarrow{E}_T = -\sum_j \vec{E}_{Tj}$ summed over all calorimeter towers $- \vec{p}_{T\mu} + \vec{E}_{T\mu}$ (dE/dx)
- Require missing $E_T > 15$ GeV for e-μ pairs

High p_T Muon candidates 9.6/fb

CDF Preliminary

$3x10^8$ events



Look for WW candidates in μe events with missing E_T

- Eliminates Drell-Yan background, like Z plus missing E_T from mismeasured jet activity.
- Major backgrounds are W + jets, where a jet fakes an electron, and t-tbar pairs. There are 3×10^6 W's. σ(t-tbar) ~ σ(WW)/2.
- Smaller backgrounds are Wγ (σ~ 2xWW), and WZ (σ~WW/3), where one e leg is lost.
- Approximate cancellation by like sign subtraction.

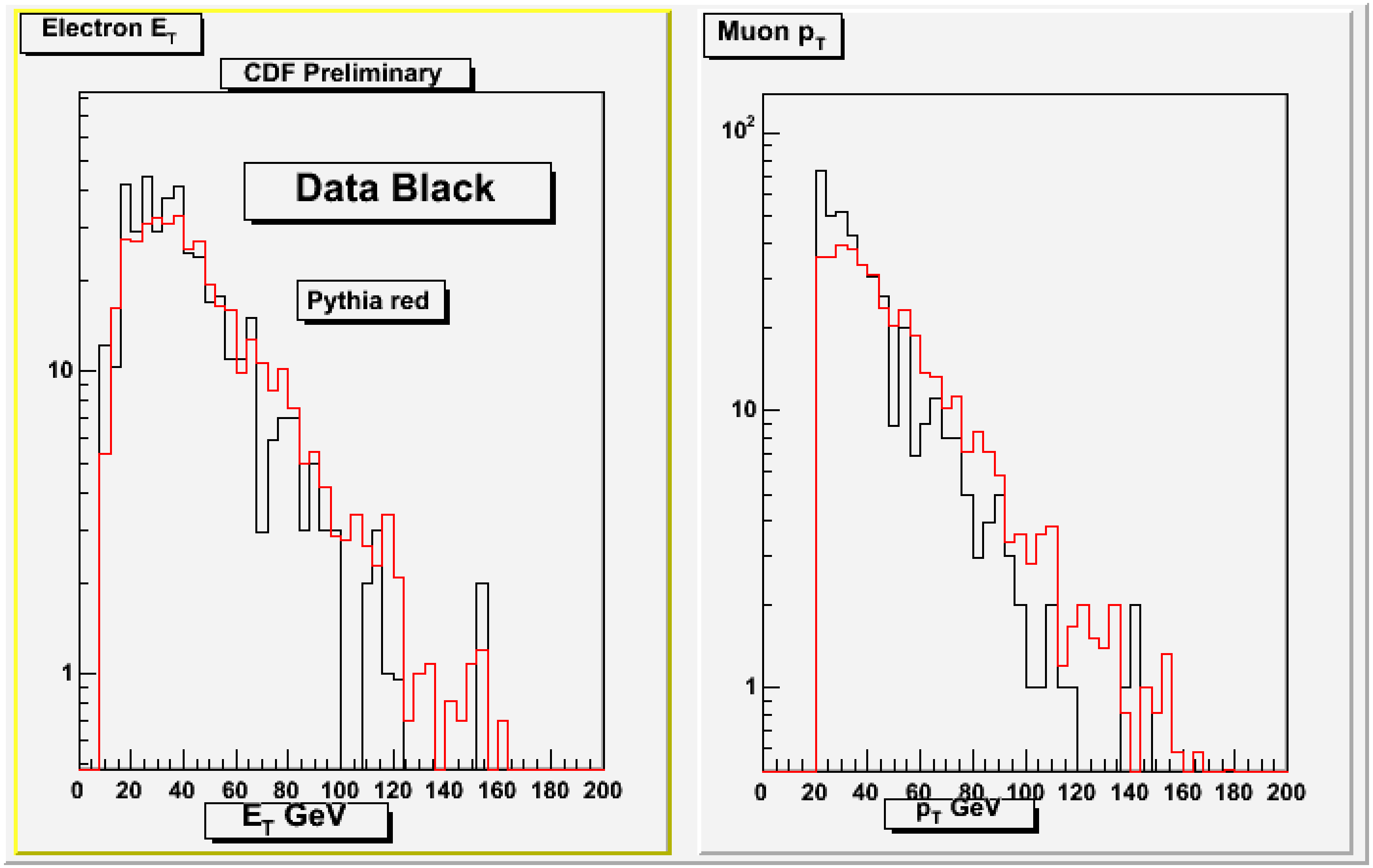
Pythia Monte Carlo comparison

- Pythia pbar+p -> W^+ + W^-, each W decays e or μ or τ. Branching fraction 0.105.
- Pythia pbar+p-> tbar + t, again each W decays e or μ or τ.
- Data sample should be 65% WW, and 35% ttbar.

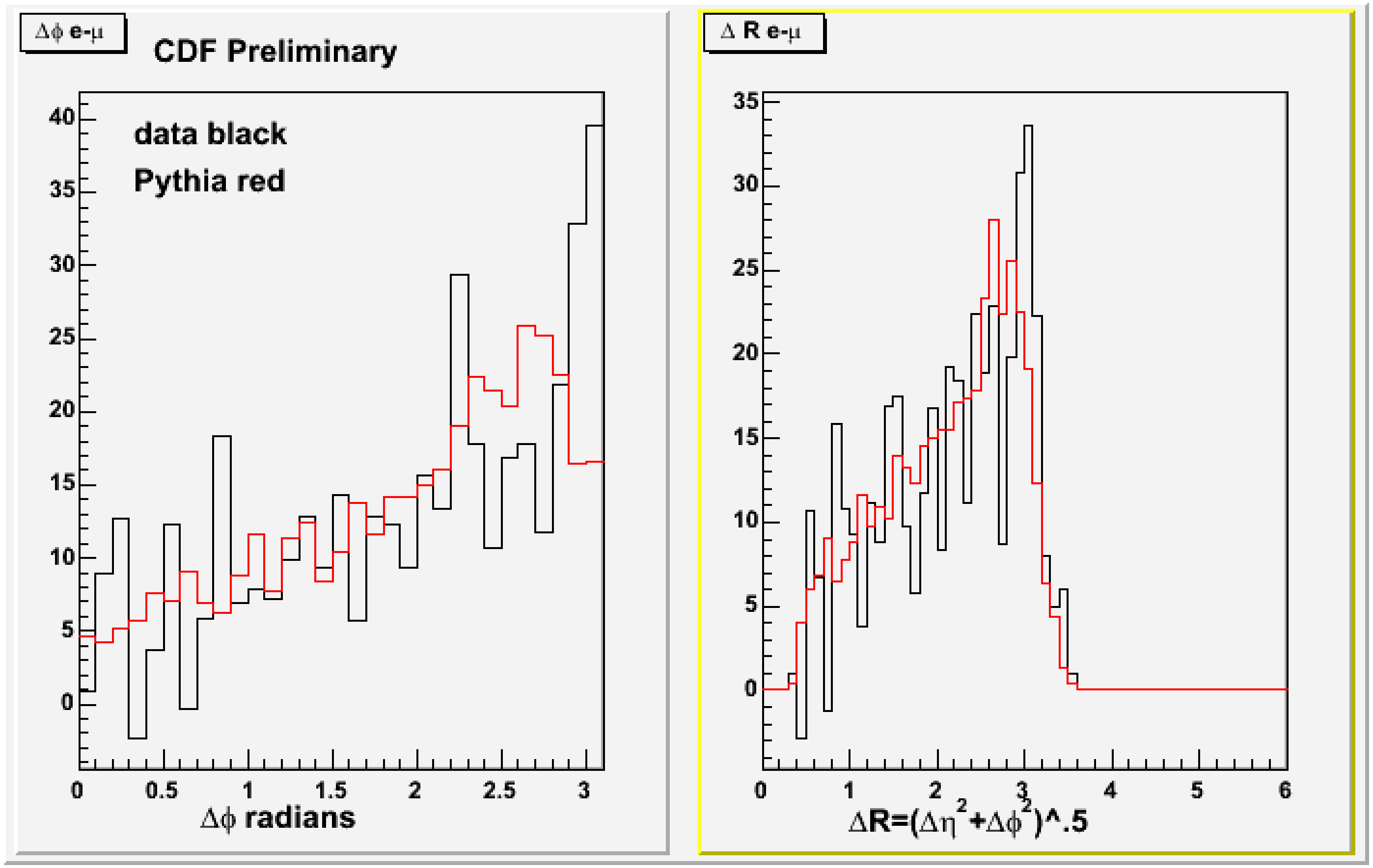
Data

- 300×10^6 high p_T muon triggers
- 658 opposite sign μ e pairs passing all cuts.
- 248 like sign μ e pairs passing all cuts (38% like sign background).
- 3×10^6 single W's -> ~300,000 W+jets, so jet -> fake electron ~0.001.
- 410 events like sign subtracted.

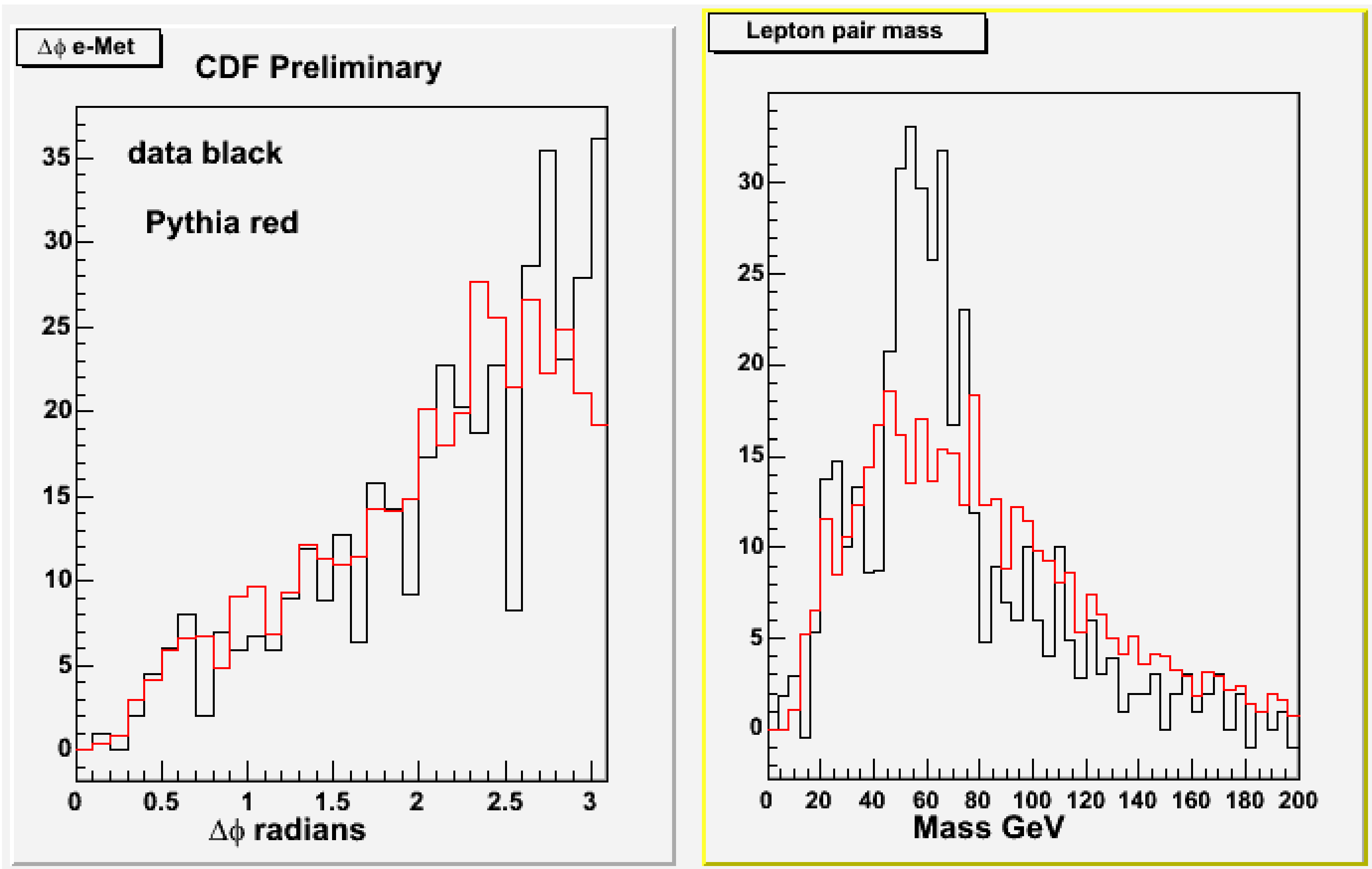
(Opp – like sign) data compared to Pythia 65%WW + 35% ttbar



Data-Pythia comparison



data –Pythia comparison



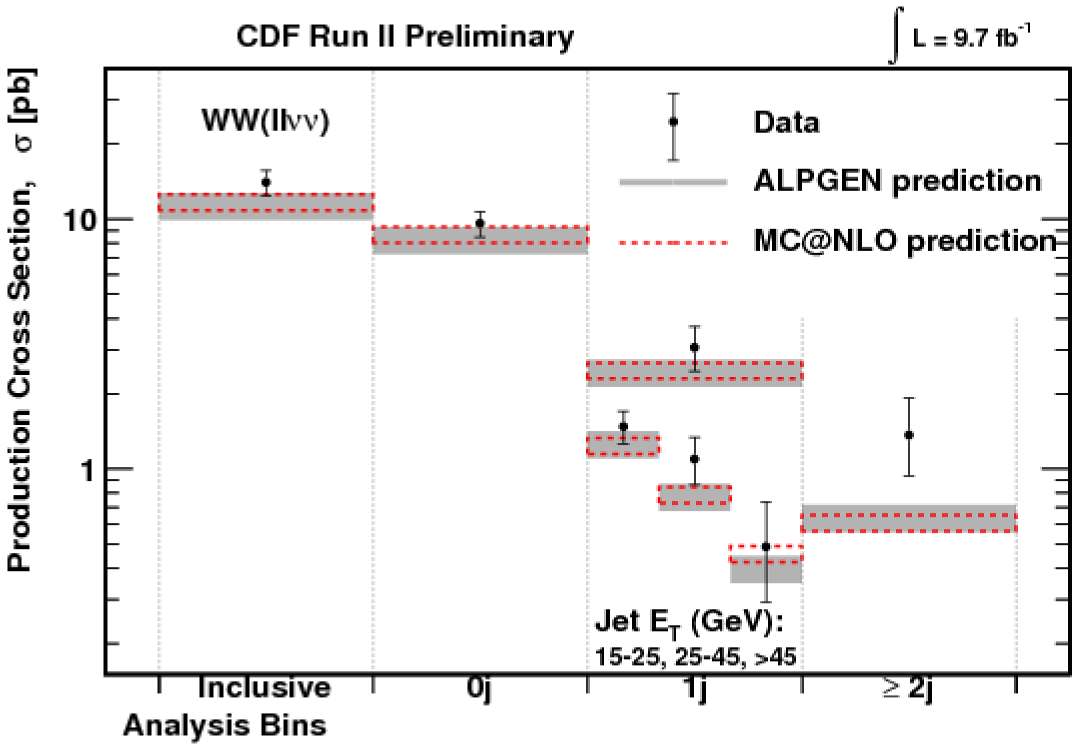
Preliminary cross section

- Using Pythia to calculate the acceptance, assuming σ (ttbar) = 7.6 $\pm$0.6 pb (D0 Tevatron)
- And floating σ(WW) gives 410 opp sign events in 9.6/fb for
- σ(pbar+p->WW+X) at 1.96 TeV = 17.6$\pm$1.8 pb
- Neural net analysis gave σ = 14.0$\pm$2.0 pb using a larger data sample (2000 events, 1000 background).

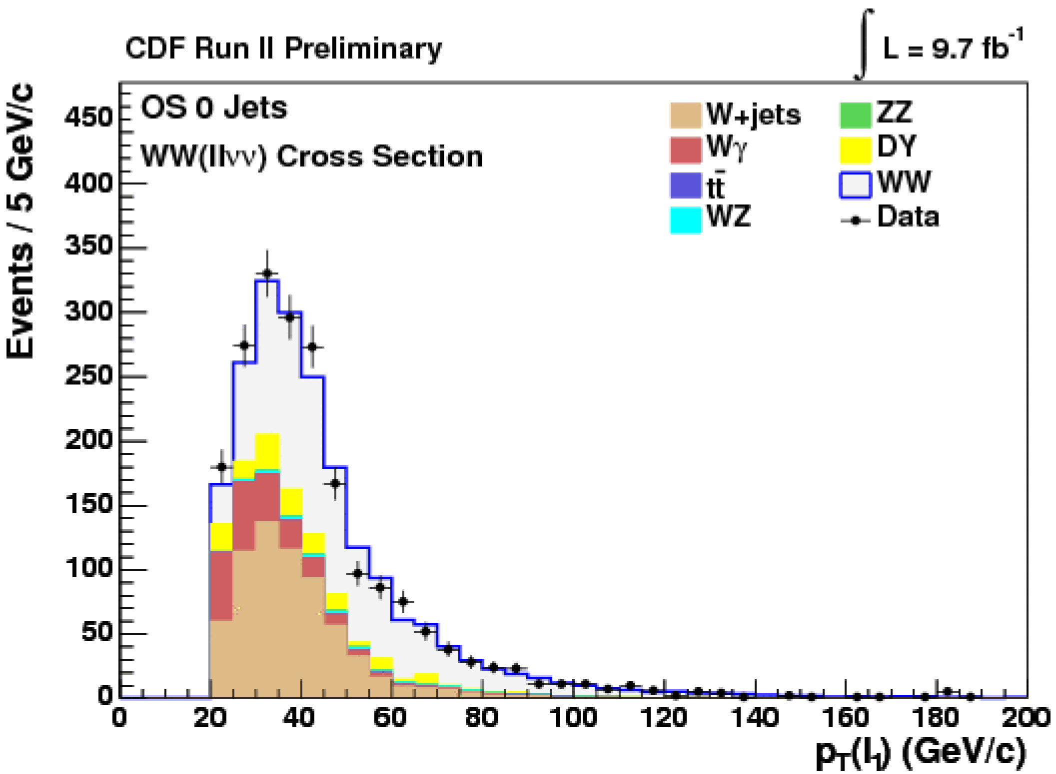
ДОПОЛНИТЕЛЬНЫЙ МАТЕРИАЛ

- Мой доклад кончается.
- Спасибо для внимания

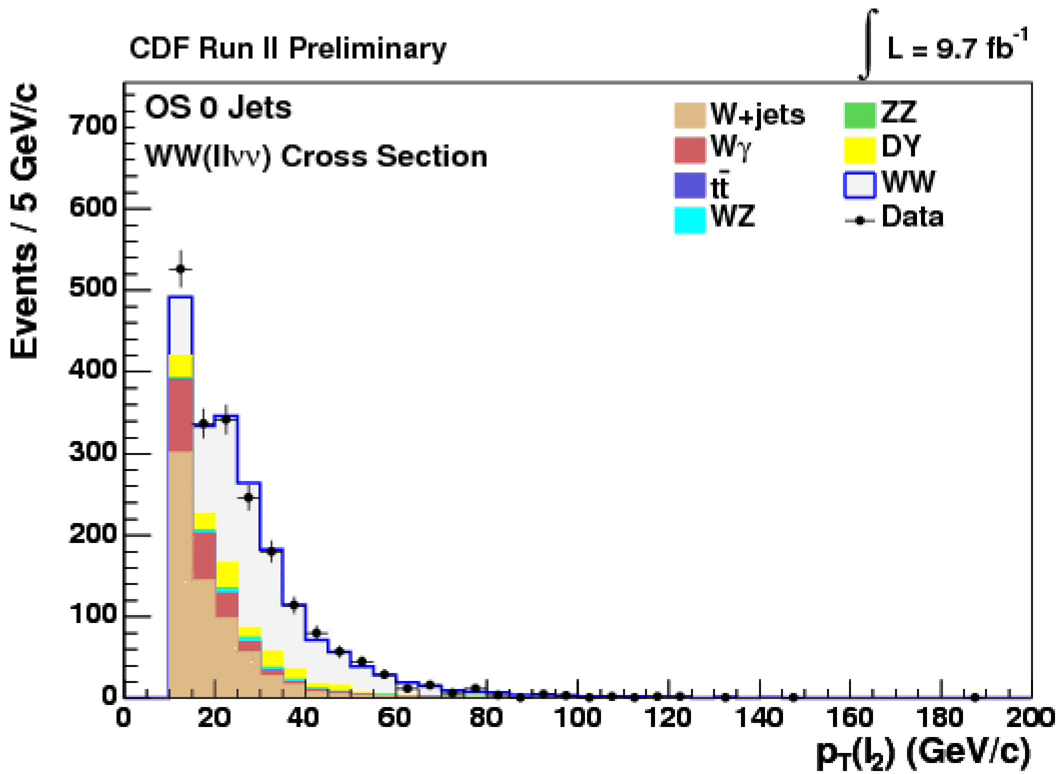
WW inclusive



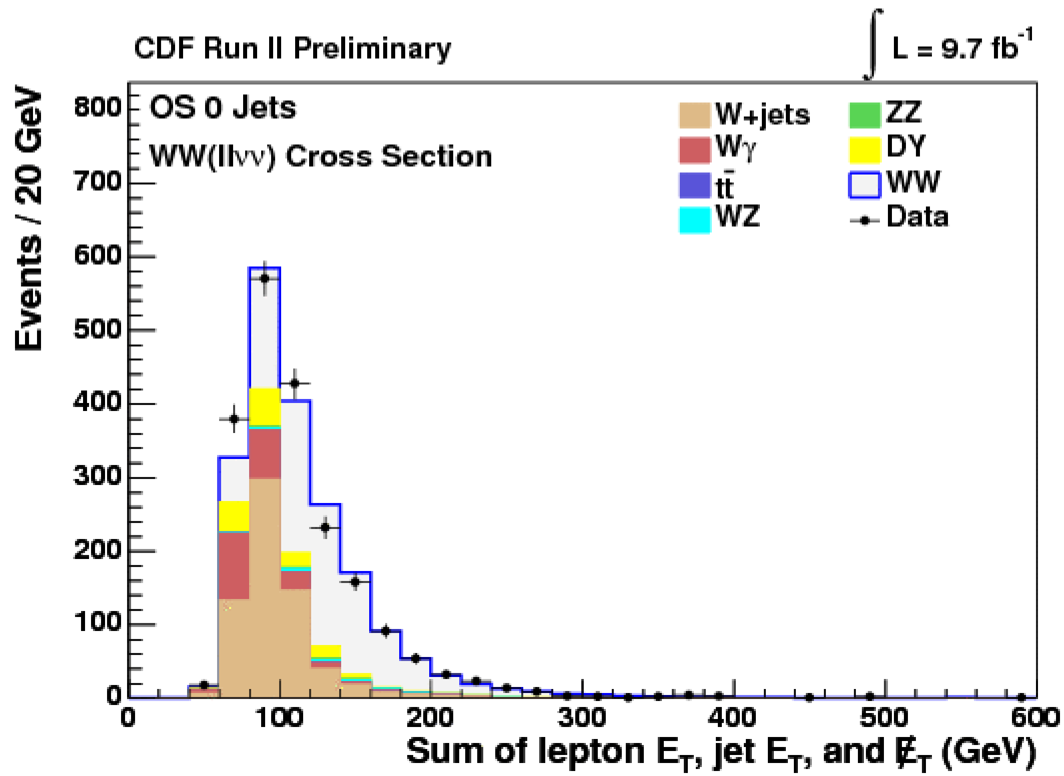
WW kinematic variables p_T of leading lepton



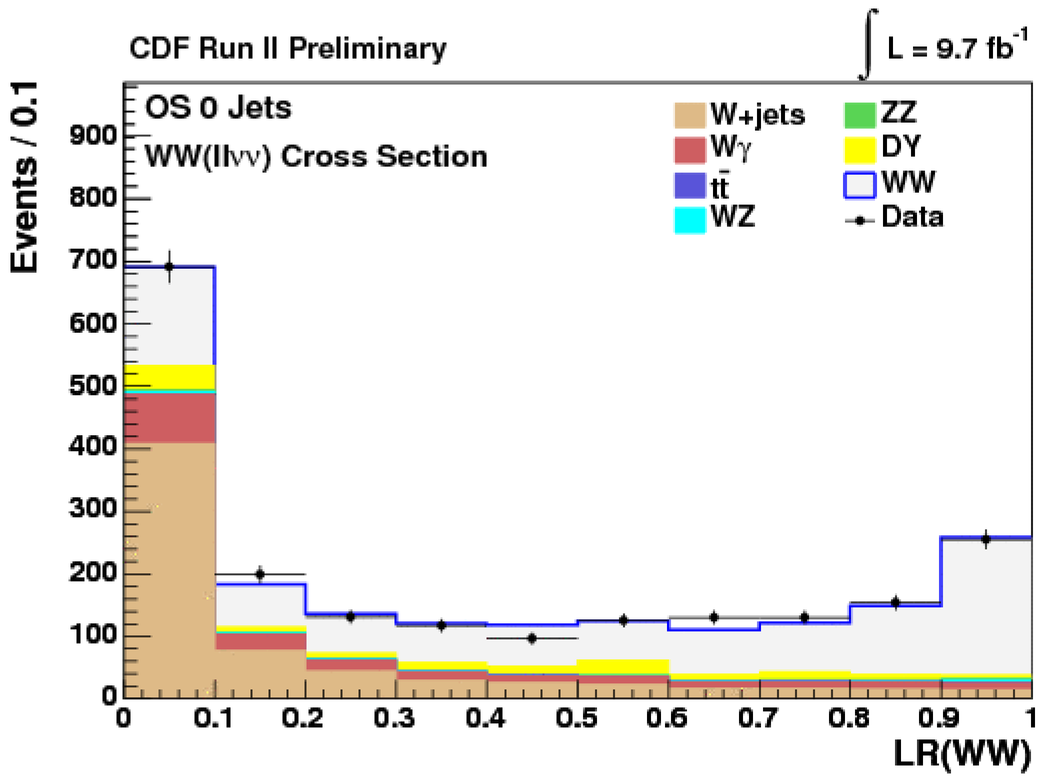
WW kinematic variables
p_T of second lepton



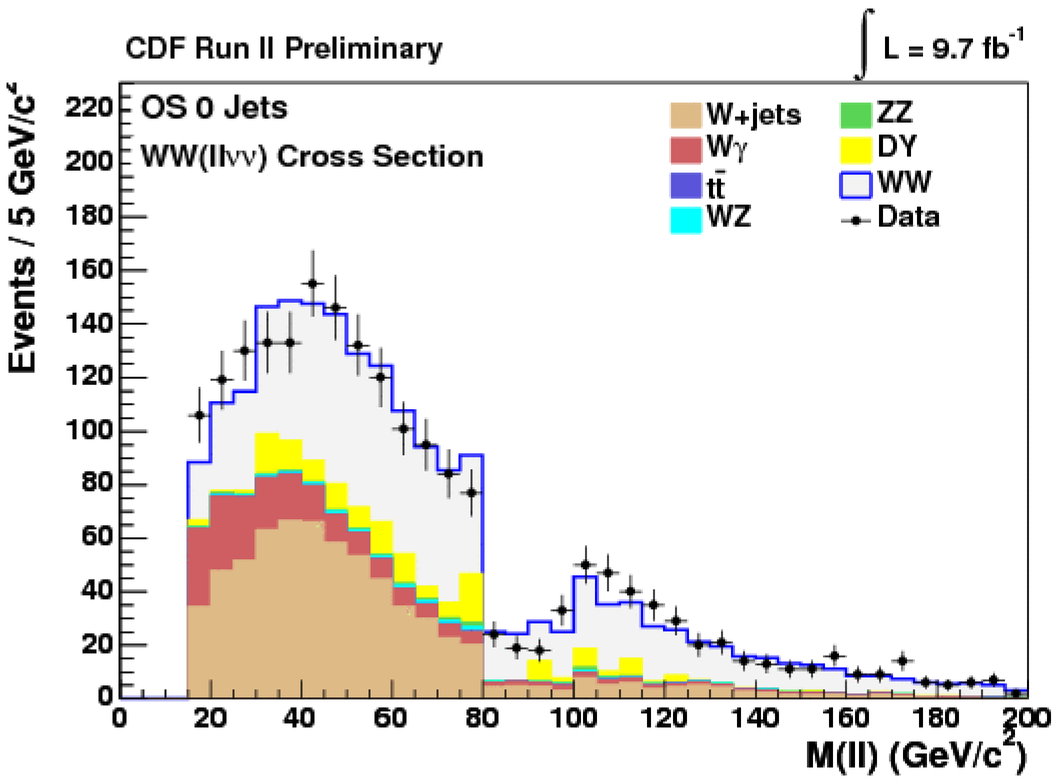
WW kinematic variables
Sum E_T leptons + jets + MeT



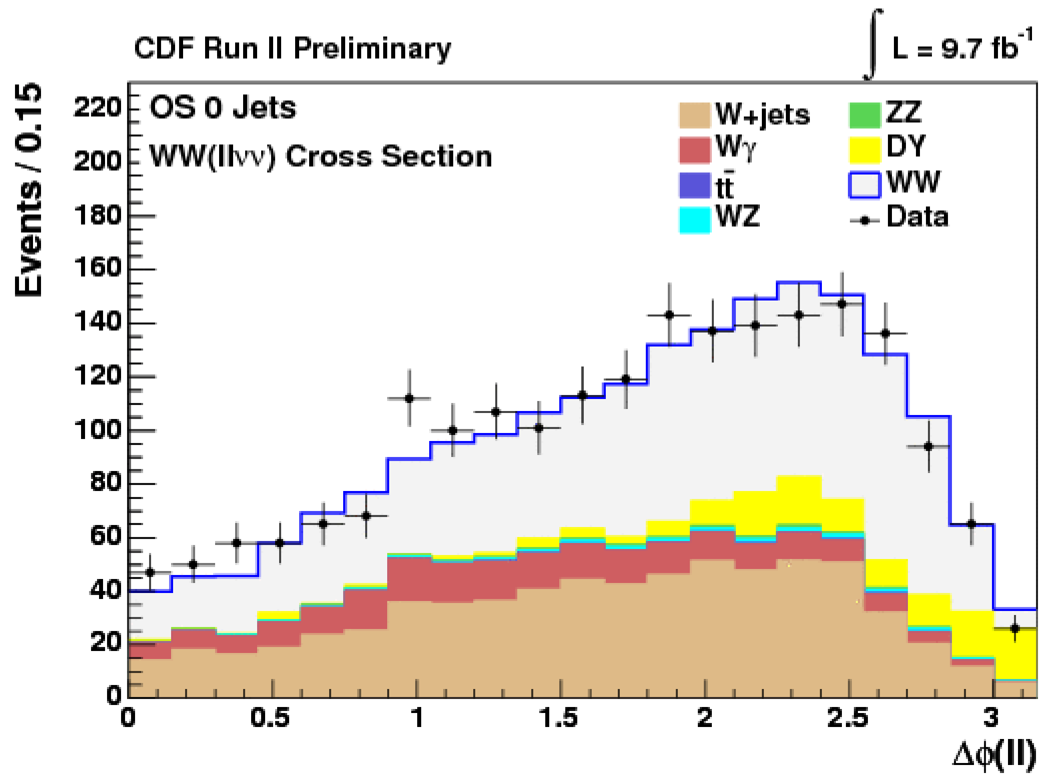
WW kinematic variables liklehood ratio



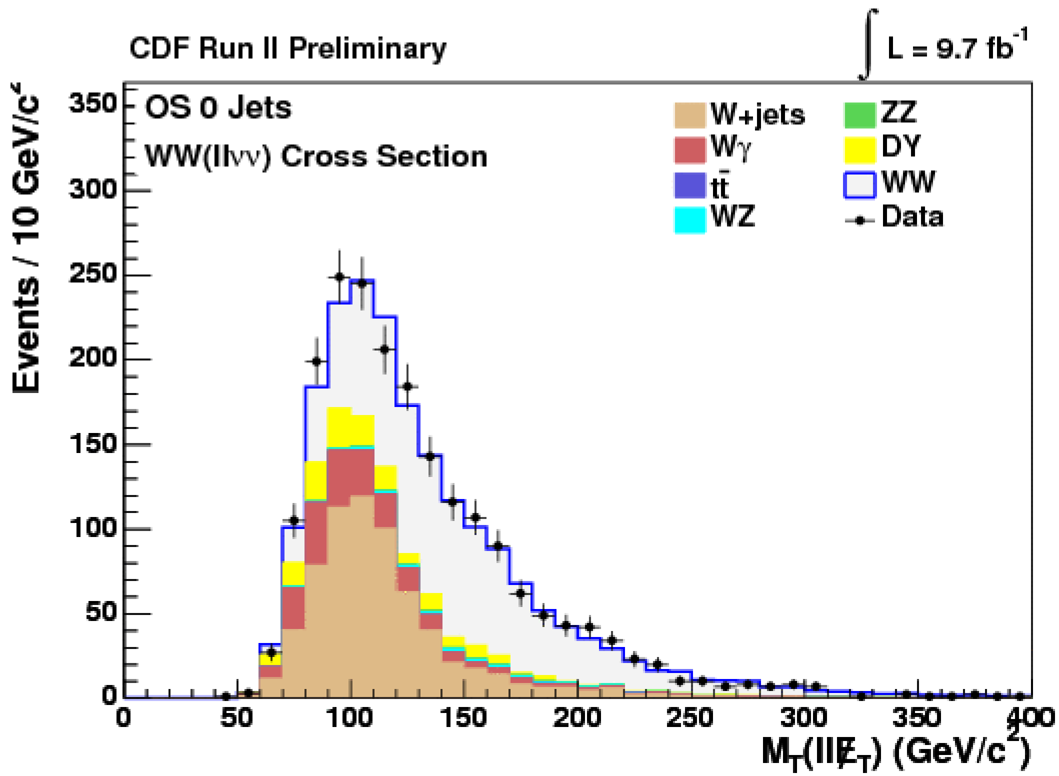
WW kinematic variables lepton pair mass



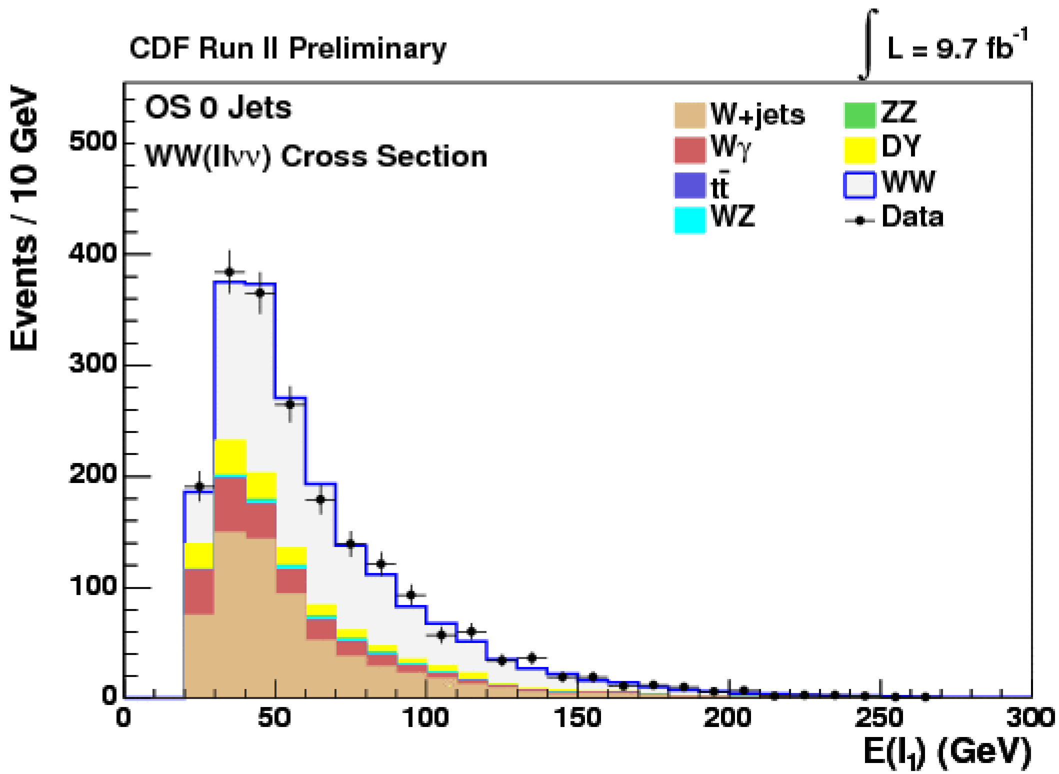
WW kinematic variables
Δφ lepton pair



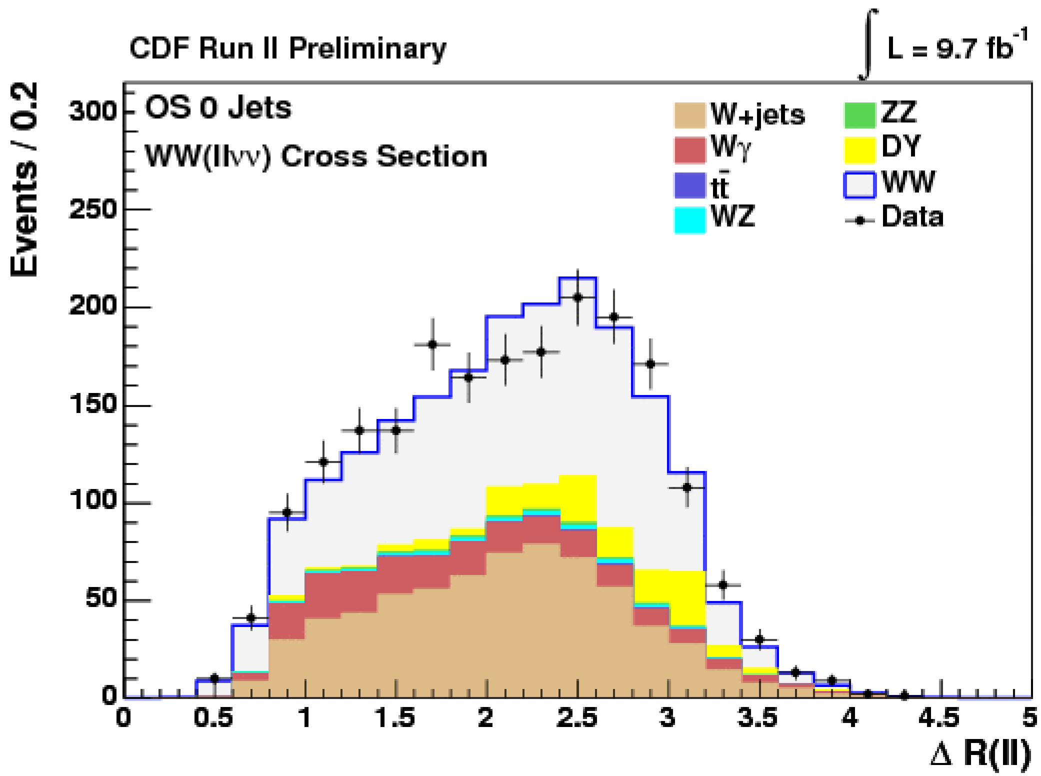
WW kinematic variables transverse mass lepton pair + Met



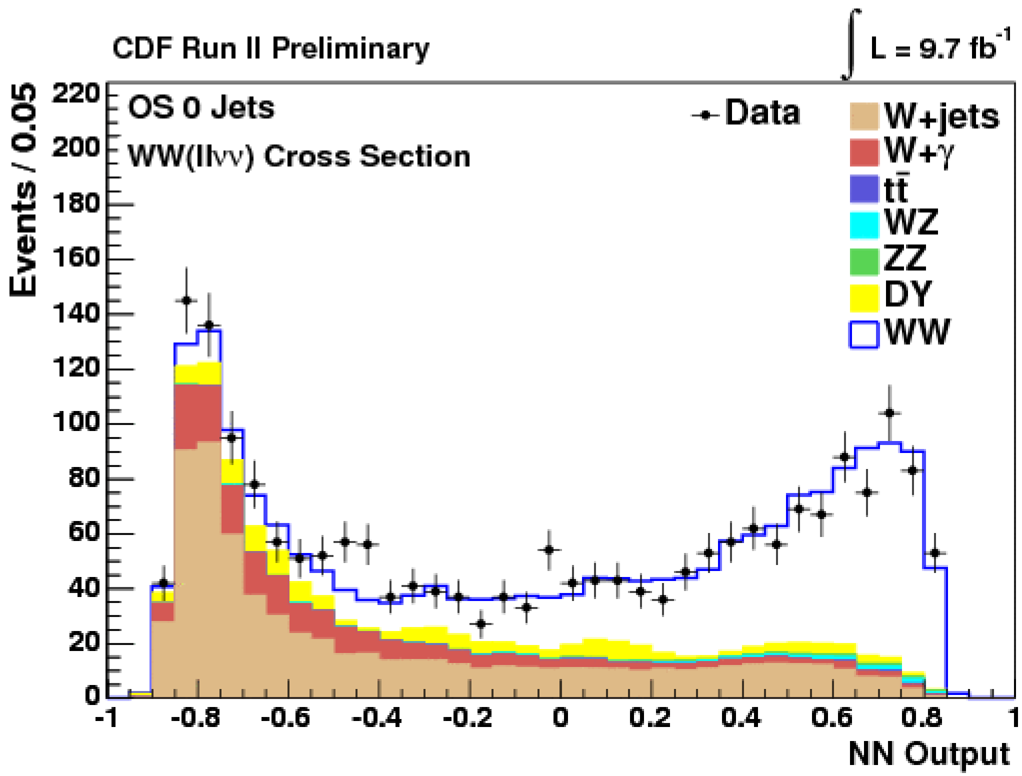
WW kinematic variables
Energy of leading lepton



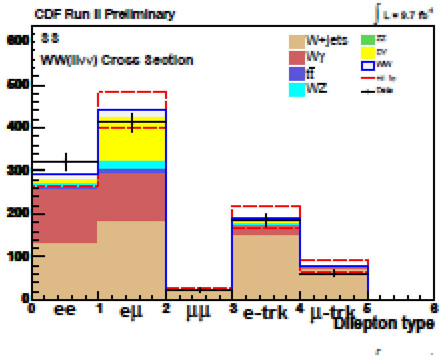
WW kinematic variables
ΔR lepton pair

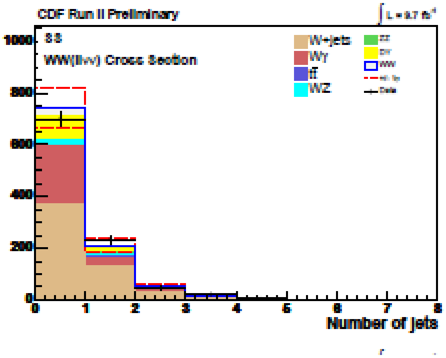


Neural net output
WW no jets with E_T>15 GeV

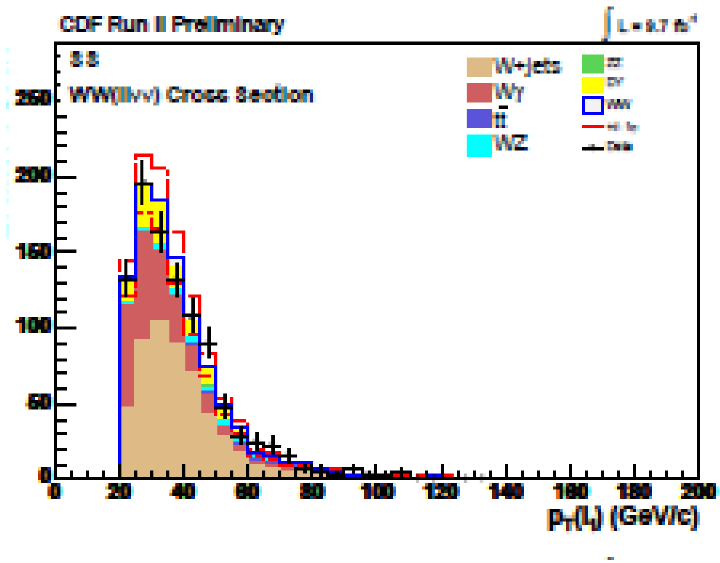


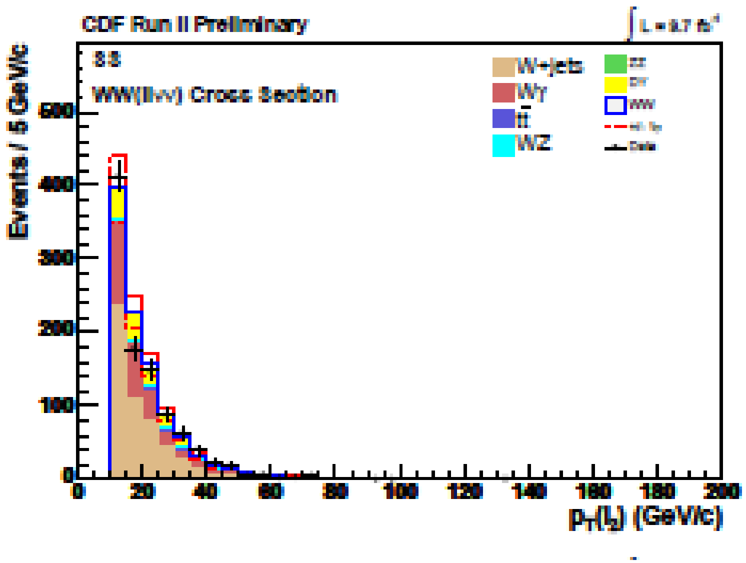
Like sign background



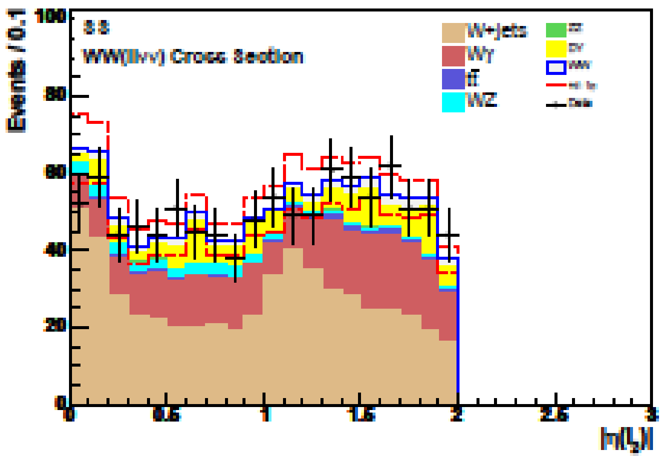


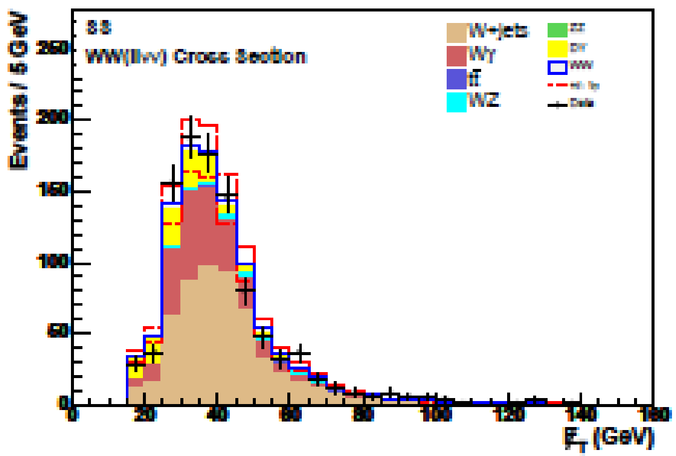
Like sign background distributions



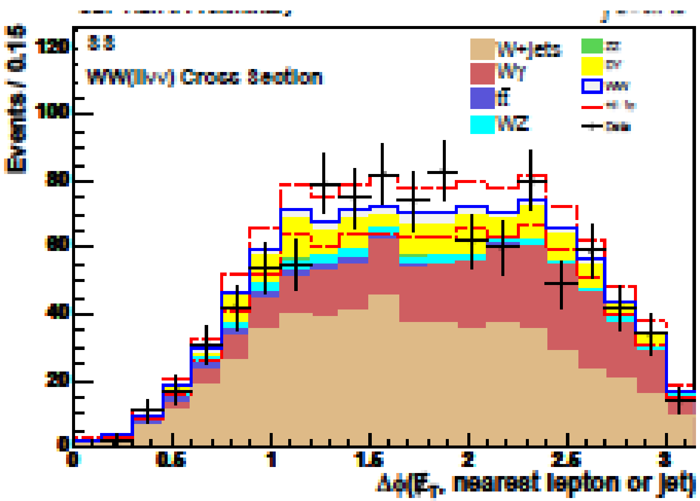


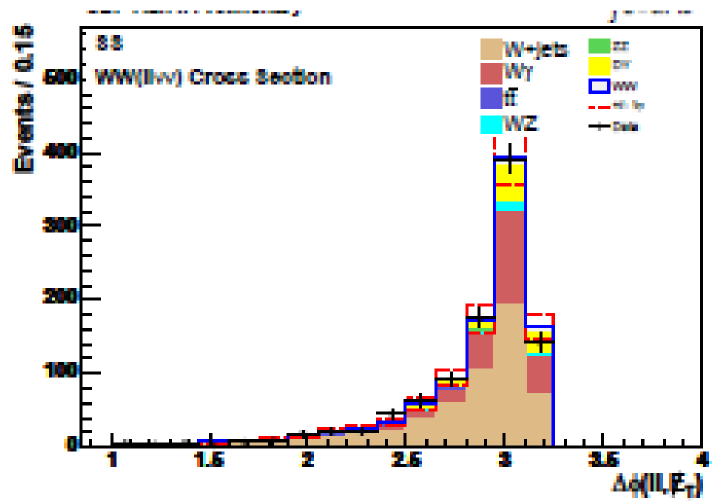
Like sign background distributions



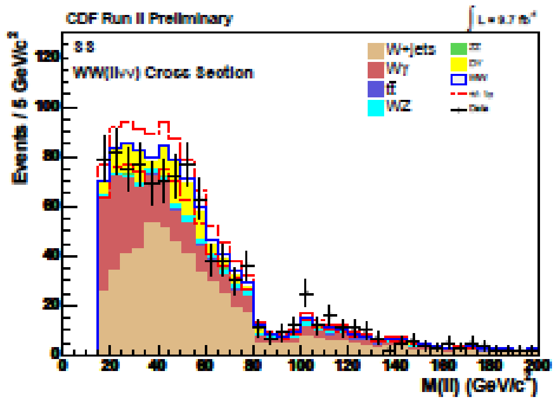


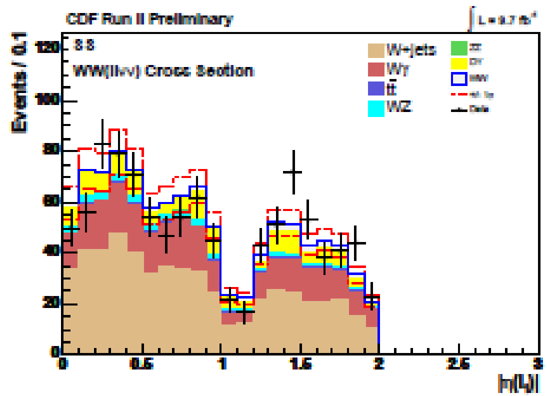
Like sign background distributions



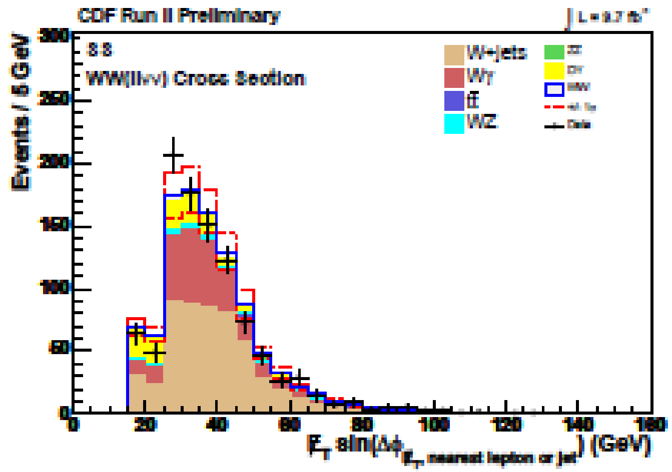


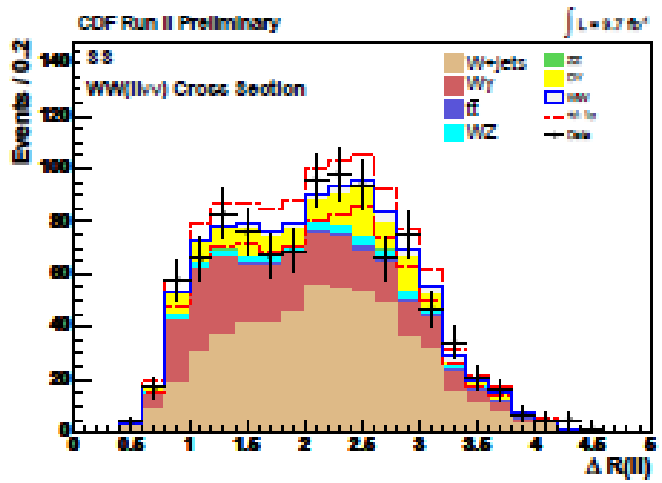
Like sign background distributions continued



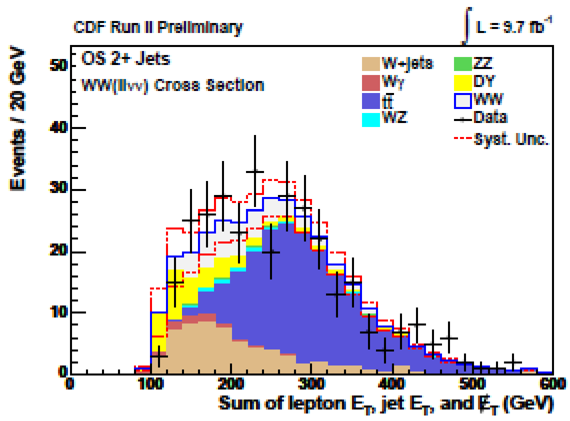


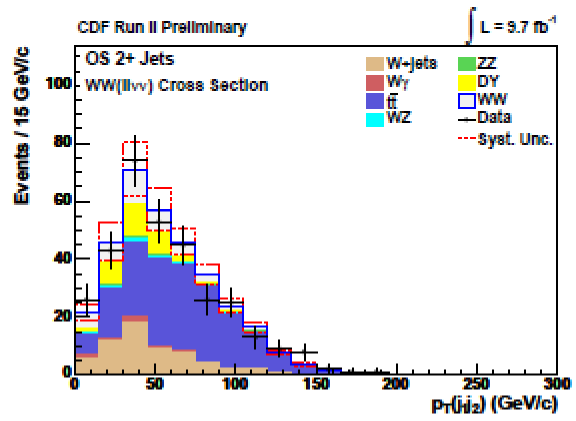
Like sign background distributions contued



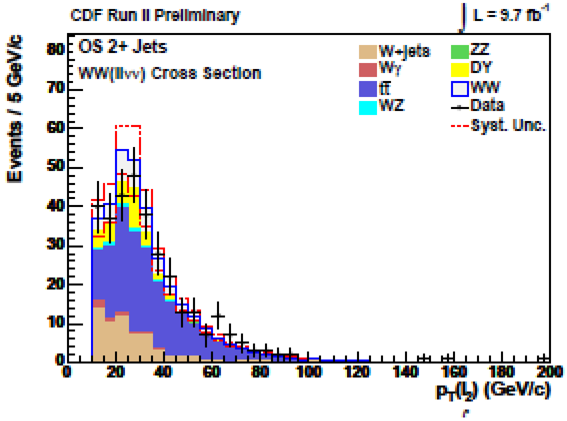


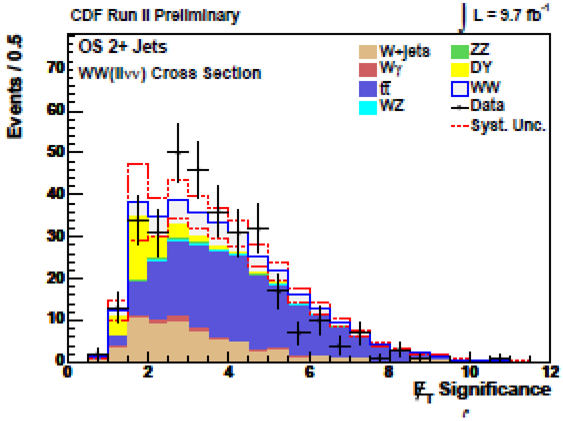
WW + two or more jets



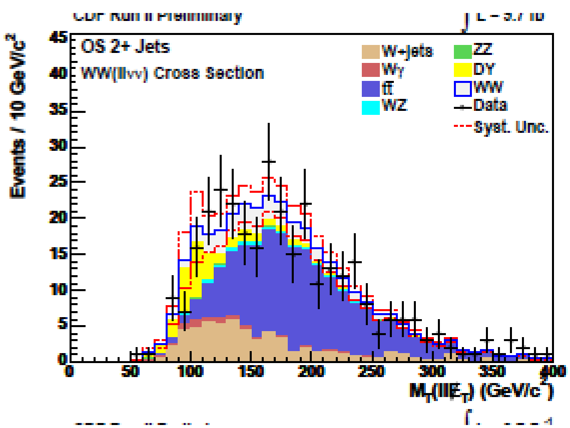


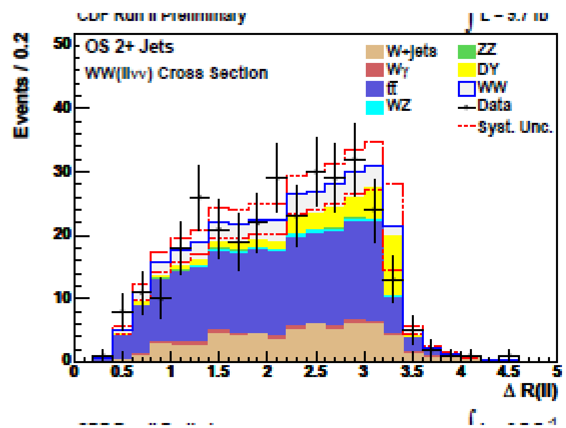
WW + two or more jets



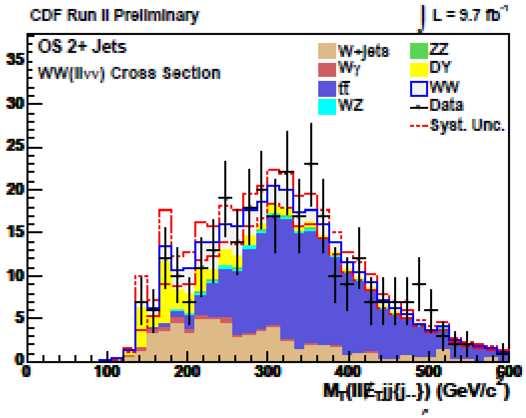


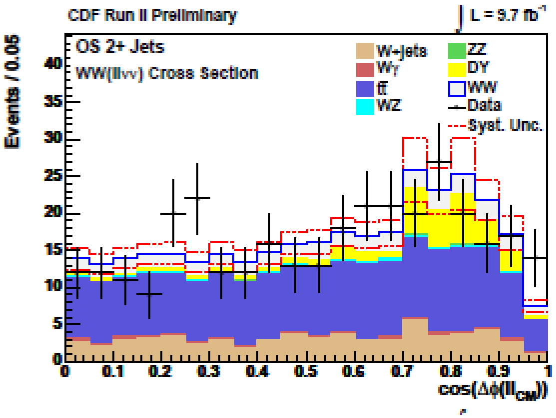
WW + two or more jets



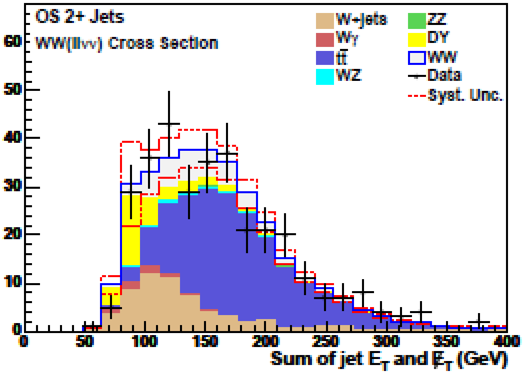


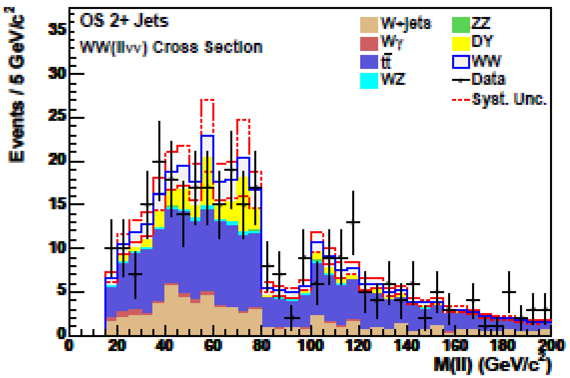
WW + two or more jets





WW + two or more jets





WW + 2 or more jets NN output